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Decomposition analysis: Change of carbon dioxide emissions in the Chinese textile industry

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ABSTRACT

We analyzed the change of energy-related carbon dioxide (CO_2) emissions in the Chinese textile industry from 1986 to 2010. Decomposition analysis based on Logarithmic Mean Divisia Index method was applied and the study period was split into five time intervals for easier data management. Results show that industrial activity and energy intensity were the main determinants of change in carbon dioxide emissions. Industrial activity was the major factor that contributed to the increase of CO_2 emissions. Energy intensity had a volatile trend interchanging intervals of growth (increasing and decreasing) along the study period. Furthermore, energy mix and carbon intensity equally decreased the CO_2 emissions. Industrial scale, despite limited effect also contributed to the increase of CO_2 emissions. In the meantime, while industrial output in the Chinese textile industry increased annually by 5% from 1986 to 2010, energy consumption grew by 4% with corresponding increase of CO_2 emissions by 2%. Finally, we provide policy suggestions that may be adopted to significantly cut down CO_2 emissions from the Chinese textile industry.

Contents

1. Introduction

In 2010, the carbon dioxide emissions in China was estimated to be 8.3 billion tons CO_2 and was equivalent to 58.8% of the global emissions [1]. Emissions increased by more than three times compared to 1990 and China has become the world's largest emitter of energy-related CO_2. Therefore, carbon dioxide has become a serious threat and raised a lot of concerns about its continual growth and potential impacts. The mitigation process requires important commitment in order to control and reduce carbon dioxide from all emitting sources. In that perspective, some projects have been initiated in the past years. In 2009, the Chinese government targeted to reduce the GHG emissions per unit GDP

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by 40–45% in 2020, compared to 2005. Furthermore, according to the Five-year plan (12th FYP, 2011–2015) China is expecting to reduce the CO_2 emissions per unit of GDP by 17% during the period 2011–2015, compared to 2010; to increase the share of non-fossil fuels in energy consumption by 11.4% and to decrease the energy consumption per GDP by 16%. As illustration of this enormous task, Li et al. [2] estimated that China will need to cut 1651 million tons of carbon dioxide emissions by 2020 in order to achieve the target of reducing CO_2 emissions per unit of GDP by 40–45% compared to 2005 (even in a slow economy growth scenario). For the past 30 years the energy consumption in textile industry has been dominated by coal consumption. This predominance of coal is quite difficult to reverse in the short-term considering that it is cheap and abundant compared to other energy sources. The growing energy demand from industries and the imperative need to sustain the economic growth are key aspects to consider for the success of emissions abatement. As prerequisite, it is important to determine the amount of CO_2 emitted by various industries and the variables influencing the CO_2 emissions. Therefore, estimation of carbon dioxide emissions in key industries such as the textile industry is getting its importance. The challenge of CO_2 emissions reduction from the textile industry is particularly important because of the rapid growth of that industry and its pillar role in the Chinese economy. Pushed up by the increasing demand on domestic and foreign markets, the textile industry is expected to continue the fast growth in the near future. In this paper, using the trend of energy consumption, we investigated the change of carbon dioxide emissions during the industrial process. In 2010, the textile industry represented 9.4% of the total gross output in the Chinese manufacturing sector, with an energy consumption estimated to be 62.045 Mtce (million tons coal equivalent) [3]. Over the study period (1986–2010), the total energy consumption in the textile industry grew by 4% annually, the total carbon dioxide emissions grew by 2% and the carbon intensity decreased by 2%.

Considering the dilemma between greenhouse emissions reduction and the target of industrial growth, it is relevant to determine factors responsible of change of carbon dioxide emissions in the Chinese textile industry. In this context, it is important to study questions such as: (i) what are the main factors that affect change of CO_2 emissions in the Chinese textile industry? (ii) What are the degrees of influence of these factors? Answers to these questions will be useful in several aspects. This paper will provide information on the aspects to focus on in order to mitigate carbon dioxide emissions, contribute to define strategies for the textile industry in order to improve its competitiveness and fill the large gap in the scientific research on carbon emissions reduction in Chinese industries. Furthermore, this paper will also give useful insight and orientation for policy interventions on carbon dioxide emissions issue and industrial development in developing countries.

2. Literature

There have been several reports about analysis of change of carbon dioxide emissions, and generally two main methods have been adopted. The first one is the environmental Kuznets curve approach. This method simulates the hypothesized relationship between environmental degradation—income; which is used to assess the growth trend of CO_2 emissions and to estimate the income turning point such as presented by Ezzati et al. [4], and He and Richard [5]. The second method commonly applied is the factor-decomposition model. This approach helps to picture the CO_2 emissions under different scenarios and to identify driving factors responsible of emissions change (economic growth, energy mix, energy efficiency, etc…) and the impact mechanism. This method has been employed by Diakoulaki and Mandaraka [6], Zhou and Ang [7], de Freitas and Kaneko [8], and O'Mahony et al. [9]. One of the earliest study about determinants of change of carbon dioxide emissions was conducted by Jiang [10], who assessed the CO_2 pollution issued by the major industries in China and suggested methods to cut down the volume of emissions. He pointed out the necessity to progressively reduce the proportion of coal consumption in the Chinese industries, and suggested that the most efficient method was to enhance the technological innovation and management. Later, Deja et al. [11] investigated the changes of CO_2 emissions and influencing drivers in the Polish cement industry. According to them, energy consumption was the main determinant of carbon dioxide emissions. Therefore, they suggested that reduction of the energy demand by technological improvements is the essential method to cut down emissions. Akbostancı et al. [12] studied the CO_2 emissions in Turkish manufacturing industry based fuel consumption data. Using Log Mean Divisia Index (LMDI) method, they found that changes in total industrial activity and energy intensity were the primary factors determining the change of CO_2 emissions. Similar results were provided by Torvanger [13] and later by Schmitz et al. [14] who assessed the energy consumption and CO_2 emissions (process, combustion and indirect emissions) of the European glass industry. Hammond and Norman [15] applied the decomposition analysis in UK manufacturing sector during the period from 1990 to 2007 to separate contributions of changes by variables output, industrial structure, energy intensity, fuel mix and electricity emission to the level of carbon dioxide emissions. They found that the principal reason of the reduction in CO_2 emissions was the decrease of energy intensity. Bhattacharyya and Ussanarassamee [16] used Log-Mean Divisia decomposition technique in order to conduct an empirical analysis on energy and CO_2 intensities in Thai industry for the period from 1981 to 2000. Their results suggested that in general energy intensity and structural changes were the main factors responsible for the decline. However, the impact of these factors was also related to the GDP growth. Hatzigeorgiou et al. [17] used two techniques for the case of Greece: Arithmetic Mean Divisia Index (AMDI) and the Logarithmic Mean Divisia Index (LMDI) techniques by decomposing the change of CO_2 emissions in income effect, energy intensity effect, fuel share effect and population effect. Results showed that income effect was responsible for increasing carbon dioxide emissions and that energy intensity effect contributed mainly to reduce emissions. There are also some studies that addressed the issue energy-related CO_2 emissions in China. Steenhof [18] applied the decomposition analysis in order to generate carbon dioxide emission baselines in China's electricity sector. He argued that fuel shifts to natural gas and nuclear energy will help to mitigate carbon dioxide emissions. Using similar methodology (decomposition analysis), Zhang et al. [19] analyzed the nature of the four factors: CO_2 intensity, energy intensity, structural changes and economic activity. Results showed that economic activity is the most important factor leading to growth of CO_2 emissions and that decrease in CO_2 emission was mainly due to the improvement in energy intensity and Carbon intensity. Guangming et al. [20] formulated a concept of industry CO_2 emissions efficiency and attempted to measure it through CO_2 emissions coefficient. Based on a panel of 18 sectors in Chongqing province, they found that eleven among them had great potentials of industry CO_2 emissions reduction. Zhang et al. [21] studied the regional difference of factors affecting change of CO_2 emissions. They found that growth of GDP caused the largest increase in carbon emissions, whereas decreasing energy intensity significantly decreased emissions. Zhao et al. [22] determined key factors of industrial carbon emissions in Shanghai area during the period 1996–2007. Using the Log-Mean Divisia Index method, these factors were quantitatively estimated and resulted that the factor of industrial output was the principal driver of industrial CO_2 emissions. In the meantime, energy intensity (representing 90%) and

industrial structure were the main determinants for the decline of carbon dioxide emissions. in the same order, Zhou et al. [23] attempted to estimate the amount of CO_2 emissions and mitigation potential from China's ammonia production. Their scenario analysis revealed the necessity to improve the energy efficiency and feedstock the structural change for cutting down CO_2 emissions. Xu et al. [24] investigated the change of CO_2 emissions in China's cement industry and its driving factors over the period 1990–2009. According to their results, growth in output is the most important factor driving up the CO_2 emissions, and structural shifts mainly drive down the CO_2 emissions. Ren et al. [25] determined factors influencing the changes in energy-related industrial CO_2 emissions for nine economic regions in China. Results showed that the rapid industrial growth, industrial structure and energy mix are important factors responsible for the increase in CO_2 emissions, while the reduction of energy intensity is the main factor driving down CO_2 emissions.

Table 1 summarizes a sample of most referred decomposition studies focusing on energy-related CO_2 emissions in China and the main factors affecting changes in CO_2 emissions. Therefore, one can observe that industrial activity is pointed as the main factor driving CO_2 emissions growth and the energy intensity as main mitigating factor.

From the literature presented, research on energy-related CO_2 emissions is still limited in China. Moreover to the best of our knowledge, no study has been conducted on change of CO_2 emissions in the textile industry despite its importance in the Chinese economy. Therefore, we aim to contribute to the existing literature by conducting an in-depth study on the factors affecting change of carbon dioxide emissions and by proposing efficient mitigation methods.

3. Overview of the Chinese textile industry and energy consumption

The Chinese textile industry is a pillar and remarkably important for the Chinese economy. Its importance is due to the fact that products are widely used in diverse sectors of the economy. Over the past 25 years, the Chinese textile industry developed rapidly. It has been mainly driven by the fast expansion of the Chinese economy and pushed up by diverse incentive policies (The 11th Five-Year Plan for the Textile Industry). The industrial output increased from 132.8 billion yuan in 1986 to 394.06 billion yuan by 2010 [3]. Yet by volume of production for instance, the manufactured fiber was estimated to be 41.30 million tons in 2010; equivalent to a growth by 60.7% compared to 2005. From 2002 to 2010, the productivity of main items such as chemical fiber, yarn, cloth and garment grew respectively by 214%, 242%, 201% and 230%; equivalent to 31 million tons, 27.3 million tons, 79 billion meters and 28.5 billion pieces [26]. Since 1980s, the Chinese textile industry expanded internationally and has become a major exporter of textile products; which contributed considerably to the China's economic development. Moreover, Chinese export of textile and apparel products reached 248 billion USD in 2011, which accounted for nearly one-third of the global textile and apparel trade volume. Similar to the rapid growth in output value, the energy consumption also raised significantly; grew from 25.15 Mtce (million tons coal equivalent) in 1986 to 62.04 Mtce in 2010 China Energy Statistical Yearbook, CEIC China Database [3,27]. During the same period, the energy-related carbon dioxide emissions grew from 55.6 to 75 Mt CO_2; equivalent to a growth for about 35% (Fig. 1).

Thus, on annual average the energy consumption increased by 4%; which drove up the CO_2 emissions by 2%. However, an important decrease in energy consumption occurred during the period of 1996–2000 and similarly there was a subsequent reduction in CO_2 emissions. This was mainly due to a recession occurred during that period (fall of industrial output by 1.8% annually); which had as consequence to restrain the energy demand by 1.3%. Similar fall occurred in 2008 and 2009 due to the consequences of the global financial crisis and led to a slight recession in the Chinese textile industry; which is highly oriented on export since China joined the WTO (World Trade Organization) in 2001. About the energy consumption structure, coal has been the main energy used in the Chinese textile industry. During the study period, the coal consumption increased by 2% annually. In the meantime, the demand for electricity and natural gas grew respectively by 8% and 60%. The proportion of coal increased continually over the years, except during the time interval 1996–2000 (Fig. 2). Similar to the decrease of energy demand, the demand for coal also reduced by 5%.

Thus, all over the years coal played a key role in the growing energy consumption. Most of the increase in the CO_2 emissions during the study period (1986–2010) derived from the coal consumption. Similarly, the reduction of coal consumption was driven by the decrease of total energy demand observed during that period. The energy diversification also led to reduce the share of coal in the total energy consumption. The Chinese textile industry is currently in a transformation process with enormous foreign investments and expertise. The textile products are becoming more and more sophisticated in recent years; which will considerably continue to influence the energy mix in the future.

Table 1
Studies of CO_2 emission change in China based on decomposition analysis.

Reference	Period	Main emission increment factors	Main emission mitigation factors
Steenhof [18]	1980–2002	*EI*	*EM*
Zhang et al. [19]	1991–2006	*IA*	*CI, EI*
Zhang et al. [21]	1995–2009	*EA, ES*	*EI*
Zhao et al. [22]	1996–2007	*IA*	*EI, IS*
Xu et al. [24]	1990–2009	*IA*	*IS*
Ren et al. [25]	2006–2010	*IA, IS, EM*	*EI*

Note: IA: industrial activity; EA: economic activity; EI: energy intensity; CI: carbon intensity; EM: energy mix; IS: industrial structure; ES: economy structure.

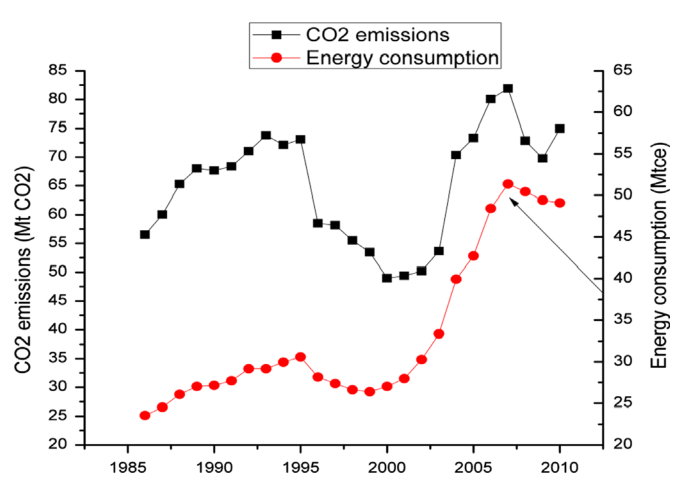


Fig. 1. Energy consumption and CO_2 emissions trends for 1986–2010.
Source: CEIC China Database [3].

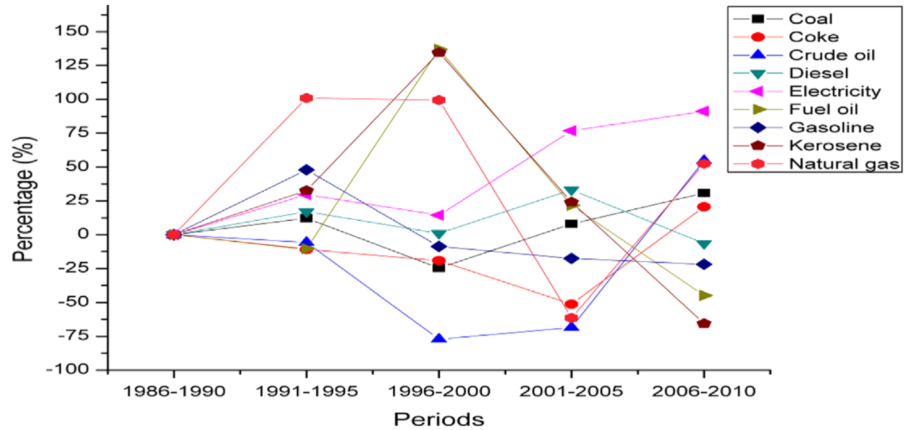


Fig. 2. Main energy sources used in Chinese textile industry by time intervals.
Source: CEIC China Database [3].

Table 2
Determinants of change of CO_2 emissions.

Variables	Determinant	Description	Items
CI	CO_2/E	Carbon intensity	CO_2: Carbon dioxide emissions
EM	E_{ff}/E	Energy mix	E: Total energy consumption
EI	E/y_i	Energy intensity	E_{ff}: Energy consumption from fossil fuels
IA	y_i/w	Industrial activity	Y: Output industrial sector, y_i: output textile industry
IS	w	Industrial scale	w: Number of employees

Note: In China, the data source of employees in particular industry is weak, the government has motivation to give out the modification. In this article, we use the industry structure to depict the increase of employees; generally, an increase in the production share in a sector implies a decrease in production share in some other sectors.

4. Methodology and data sources

4.1. Methodology

Using a Kaya-type identity, carbon dioxide emissions can be decomposed into several determinants [28]. We employed the decomposition analysis approach in order to capture the impact of factors influencing change of CO_2 emissions trend in the Chinese textile industry. Widely used, the LMDI (logarithmic mean Divisia index) along with the refined Laspeyres index has been identified as the most robust method. This is mainly because the results obtained are free of residuals [29]. It is also appropriate to apply for the formulation and interpretation of results. It is based on robust theoretical foundations allowing consistency in the results both in additive and multiplicative forms [30].

Based on these qualities, we chose to apply this method in order to provide a clear view on the degree of influence of the variables (summarized in Table 2).

The carbon intensity is expressed as the quality of energy consumption in the industry. It is formulated as the ratio of CO_2 emissions over the total energy consumption during a period. The energy intensity is formulated as the ratio of energy consumption over the industrial output. It is usually influenced by factors such as technology, energy price and labor productivity [31,32]. The energy mix represents the level of diversification of energy. In other words, it is the change in energy composition during a period. It measures the effects of shifting patterns of fuel consumption among sources of energy. The industrial structure indicates the relative weight of the output in a particular industry over the industrial output of the manufacturing sector. It reflects the change of the structure in the Chinese textile industry, we use the industry structure to depict the increase of employees. The industrial activity represents the economic performance in the industry. It is equivalent to the per capita industrial output in the Chinese textile industry.

Following Bacon and Soma [33], CO_2 emissions are expressed as follows:

$$CO_2 = (CO_2/E) \times (E_{ff}/E) \times (E/y_i) \times (y_i/w) \times (w) \tag{1}$$

$$CO_2 = CI \times EM \times EI \times IA \times IS \tag{2}$$

so

$(1) = (2)$

The change of CO_2 emissions during a period t is equivalent to the sum of effects linked to change in each determinant: the carbon intensity (CI_{eff}), the fossil fuel share in energy (EM_{eff}), the energy intensity (EI_{eff}), industrial activity (IA_{eff}), industrial structure (IS_{eff}).

$$\Delta CO_2 = CO_{2_t} - CO_{2_{t-1}} = CI_{eff} + EM_{eff} + EI_{eff} + IA_{eff} + IS_{eff} \tag{3}$$

Using the logarithmic mean Divisia index, respective effects were calculated from the following expressions:

$$CI_{eff} = (CO_{2_t} - CO_{2_{t-1}}/\ln(CO_{2_t}/CO_{2_{t-1}}) \times \ln(CI_t/CI_{t-1}) \tag{4}$$

$$EM_{eff} = (CO_{2_t} - CO_{2_{t-1}}/\ln(CO_{2_t}/CO_{2_{t-1}}) \times \ln(EM_t/EM_{t-1}) \tag{5}$$

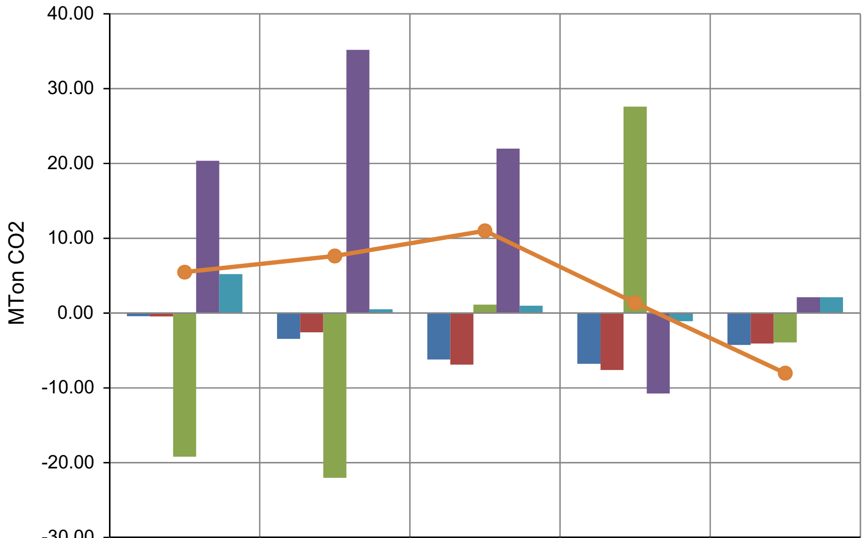
$$EI_{eff} = (CO_{2_t} - CO_{2_{t-1}}/\ln(CO_{2_t}/CO_{2_{t-1}}) \times \ln(EI_t/EI_{t-1}) \tag{6}$$

$$IA_{eff} = (CO_{2_t} - CO_{2_{t-1}}/\ln(CO_{2_t}/CO_{2_{t-1}}) \times \ln(IA_t/IA_{t-1}) \tag{7}$$

$$IS_{eff} = (CO_{2_t} - CO_{2_{t-1}}/\ln(CO_{2_t}/CO_{2_{t-1}}) \times \ln(IS_t/IS_{t-1}) \tag{8}$$

t is the period. There are five time intervals: 1986–1990, 1991–1995, 1996–2000, 2001–2005 and 2006–2010.

The industrial scale effect (IS_{eff}) measures the impact of change in industrial scale. When the proportion of output increases in a



	1986-1990	1991-1995	1996-2000	2001-2005	2006-2010
CI	-0.43	-3.45	-6.20	-6.78	-4.26
EM	-0.46	-2.56	-6.90	-7.60	-4.07
EI	-19.19	-22.03	1.13	27.59	-3.93
IA	20.35	35.17	21.99	-10.74	2.12
IS	5.20	0.50	0.98	-1.10	2.11
CO2	5.47	7.64	11.00	1.36	-8.03

Fig. 3. Decomposition of change of energy-related CO_2 emissions in the Chinese textile industry.

sector, the output share decreases in another sector. It also means an increase in population in a sector implies expansion in this industrial sector decrease in some other sectors. The energy mix effect (EM_{eff}) provides the net impact of change in fossil fuel share in the textile industry. Change in fossil fuel share, such as more consumption of coal (with high emissions coefficient) will lead to increase the contribution of this effect to the growth of carbon emissions. The industrial activity effect (IA_{eff}) detects the influence of change in output on the emissions level. The energy intensity effect (EI_{eff}) measures the effect of change in energy intensities: which can rise or decline. Compared to other effects, its estimation depends on range wider variables. The carbon intensity effect (CI_{eff}) captures what would have been the change in CO_2 emissions if the fossil fuel mix changed, but all other factors remained constant. All effects were also estimated similarly. By this decomposition method, the total change in CO_2 emissions is obtained by the sum of effects.

4.2. Data sources and assumptions

This study is based on annual data covering the period from 1986 to 2010. Data were collected from China Statistical Yearbooks, China Labor Statistical Yearbooks, CEIC China Database 2012, and China energy statistical yearbooks. The CO_2 emissions coefficients of energy sources (coal, coke, crude oil, diesel, fuel oil, gasoline, kerosene and natural gas) were chosen according to their estimations made by the Intergovernmental Panel on Climate Change IPCC (2006). Carbon dioxide emissions were estimated by multiplying consumption of individual fuels by their CO_2 emission coefficients. Data about China's textile industry were calculated based on 1990 constant prices. However, this study has some limitations. It is relevant to notice that the application of decomposition methodology is sometimes linked with some imperfections due to the use of current values for energy content, conversion rates and emission factors in defining the emission performance of the energy in a time-series analysis. Generally, the choice of time intervals is based on the policy changes or energy mix transition. Thus, inappropriate intervals may lead to loss of accuracy in the analysis [34]. We split the study period (1986–2010) into five-year time intervals for easier data management while performing the decomposition analysis by observing the nature of factors affecting change in CO_2 emissions and to capture changes in energy policies occurred in China during each time interval. Similar procedure was adopted in previous studies conducted by Zhang et al. [19,21].

5. Empirical analysis

The application of the decomposition analysis provided the degree of influence of determinants of the change in energy-related CO_2 emissions during the period 1986–2010 (Fig. 3). The contributions of these factors were analyzed by splitting the study period into five time intervals.

Results of the decomposition analysis show that there has been significant changes of carbon emissions trend in the Chinese textile industry. It is therefore necessary to identify the reasons, so that appropriate measures can be designed for mitigation. Results show that industrial activity effect and energy intensity effect were the main determinants of the change in energy-related CO_2 emissions. Production output growth (industrial activity) was the most important factor that led to the increase of carbon dioxide emissions. The energy intensity effect (*EI*) had a volatile trend interchanging intervals of increase and decrease along the assessed period but was the major cause for the reduction of carbon emissions. Moreover, energy mix effect (*EM*) contributed significantly to cut down emissions. We observe that during the first two time intervals (1986–1990 and 1991–1995), the contribution of changes in production output (industrial activity effect) to the change in emissions was the highest among the variables (20.35 and 35.17 respectively)

followed by the energy intensity effect (−19.19 and −22.03 respectively). During the period 1996–2000, the industrial activity decreased but continued to be the most influencing factor (21.99), followed by the energy mix effect (−6.90) and carbon intensity effect (−6.20). Therefore, during the first three interval periods (from 1986 to 2000) the industrial activity effect was continually the most important factor driving up the carbon emissions, whereas the energy intensity effect (improvement in energy efficiency) led to decrease emissions except in 1996–2000. Similarly, during 2006–2010 the industrial activity effect pushed up the emissions even though its impact considerably reduced. The carbon intensity, energy mix and energy intensity were the most important factors that drove down the carbon emissions. However, we denote a disruption during the third and fourth period on which energy intensity effect led to increase emissions, whereas carbon intensity and energy mix continued to decrease the emissions. In general, in case of absence of intensity reduction, industrial activity in textile sector would have led to a much greater increase in carbon emissions than actually observed. For instance during 1986–1990, the industrial activity effect would have led to increase the CO_2 emissions from 51.05 Mtce to 71.4 Mtce (million tons coal equivalent) if the structure, energy intensity, energy mix and carbon intensity had remained constant at 1986 levels. On the contrary, the energy intensity effect would have reduced emissions to 31.86 Mtce during the same period. The pattern of energy intensity reflects a possible relation with the economic activity in the textile industry. During a period of expansion, it was also observed a decline in energy intensity and vice-versa. Such of increase in energy intensity was due to a loss in energy efficiency and inadequacies of measures implemented in order to improve the technology, output and energy saving. Similarly, a case of decline in energy intensity reflects good performance related to technology, tension on energy price, high productivity and generally the effect of efficiency in energy conservative measures. Throughout the study period, the industry structure effect was not very high, but contributed mostly in increasing carbon emissions (except during the time interval 2001–2005); which is similar to the results provided by Reddy and Ray [35]. This implies that the Chinese textile industry has become more carbon-intensive. The energy mix effect has considerably decreased carbon emissions throughout the study period. Measures of shifting from fossil fuel consumption to less polluting energy sources brought positive results for the mitigation of carbon emissions. The decrease in carbon intensity is the evidence that important progress have been made in adjusting fuel mix in textile industry. The share of energy from fossil fuels to the total energy consumed reduced from 81% in 1986 to 44% in 2010 [27]. Through that period, almost half of the energy traditionally used in the industry processes were replaced by less polluting energy sources. As illustrated, the textile industry consumed 30 million cubic meter of natural gas in 1986 and by 2010 the amount considerably increased to 166 million cubic meters [3]. However, there was a decline of the energy mix effect during the period of 2006–2010. This was due to the growth in coal and coke consumption during that period. The decrease of carbon intensity can be explained by efforts made toward developing large-size of textile production units. Moreover, the slight increase of carbon intensity (−4.26) during that period compared to previous time intervals was due to the substantial growth in coal consumption. The fast growth of textile industry along the study period has been an important reason explaining the growth of carbon emissions. According to the results, decrease of carbon emissions in China's textile industry has mainly resulted from improvement in energy intensity, carbon intensity and energy mix. These findings show that efforts should be made on adjusting the industry structure and that further improvements of energy intensity are necessary in order to have continual decreasing effect on carbon emissions.

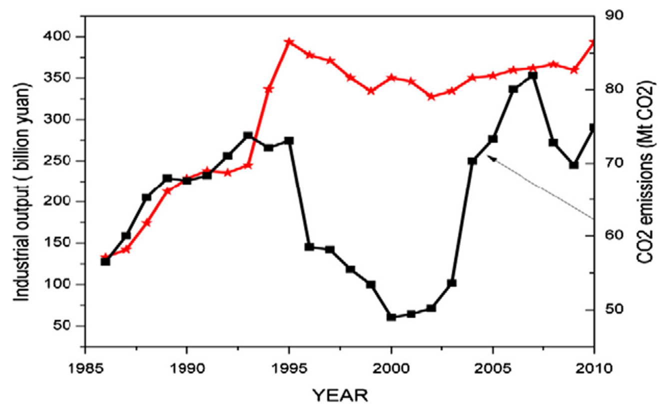


Fig. 4. Comparison of CO_2 emissions and industrial output trends in Chinese textile industry.
Source: CEIC China Database [3].

6. Comparison of carbon emissions change among time intervals

The decomposition analysis has shown that in general rapid growth of industrial activity is the main driving force responsible for carbon emissions in textile industry. Moreover, the poor adjustment of the industrial structure pushed up the carbon emissions, principally during the first time interval. However, important measures such as shutting down small and inefficient production units and concentration among viable production units led to slight decrease of the impact of industrial structure along the time intervals. The energy intensity effect decreased emissions during periods 1986–1990 and 1991–1995, increased emissions from 1996 to 2005, and decreased emissions again from 2006 to 2010. The decreased emissions resulting from improved carbon intensity (decoupling of industrial growth and carbon emissions was due to a reduction in energy intensity caused by improved energy efficiency) and optimization of the energy mix. The Chinese textile industry observed a remarkable disruption about the contribution of the industrial activity to the reduction of CO_2 emissions. From 1986 to early 1990s, the industrial output and CO_2 emissions evolved in a similar trend. However, there was a divergence occurred in periods 1996–2000 and 2006–2010. The decrease of CO_2 emissions was proportionally more important that the decrease in output. This situation was due to the decrease in production output occurred during these periods (Fig. 4); which cut down the emissions by reducing the energy consumption.

The energy intensity effect led to an important increase of carbon emissions during the period 2001–2005. The data indicated a slow-down in energy intensity improvement; which increased from 3.84 tce/yuan in 1997 to 6.96 tce/yuan in 2005. During the last period 2006–2010, Chinese government implemented measures to reduce the energy consumption and improve the energy efficiency in most of huge industries, which resulted in important decrease in the growth rate of carbon emissions during that period (11th five-year plan). For instance, the Top-1000 Energy-Consuming Enterprises program was implemented by the Chinese government in order to reduce energy consumption per unit of GDP by 20% between 2005 and 2010. This plan was targeting 1000 enterprises (including important number of textile production enterprises) accounting for 47% of industrial energy consumption in 2004. This program contributed to drive down carbon emissions during that period. Moreover, since 2001 the effect of energy mix greatly reduced the carbon emissions per unit of output in textile industry, which also led to reduce the impact of production output growth on the carbon emissions when compared to the first three time intervals.

7. Conclusions and policy suggestions

We investigated the change of energy-related carbon dioxide emissions pattern in the Chinese textile industry. Application of decomposition analysis based on the Logarithmic Mean Divisia Index provided appreciable quantitative analysis on how changes in energy intensity, industrial activity, industrial scale, energy mix and carbon intensity influenced the energy consumption and the carbon dioxide emissions from 1986 to 2010. Results show that industrial activity effect and energy intensity effect were the main determinants of the change in energy-related CO_2 emissions. The industrial activity effect contributed significantly to increase the emissions level. The energy intensity effect had a volatile trend interchanging intervals of increase and decrease along the assessed period but was the major cause for the reduction of carbon emissions. Moreover, fuel diversification (energy mix effect) played an important role in the reduction of carbon dioxide emissions. Yet, the industrial scale effect despite limited effect contributed to increase emissions. Among all types of energy consumed, coal was the predominant energy source resulting in the highest carbon emission coefficient. This large proportion of consumed energy directly led to a significant increase of carbon emissions. All over the study period, the energy intensity slightly declined from 8.8 tce/yuan in 1986 to 7.32 tce/yuan in 2010, whereas the CO_2 emissions intensity dropped from 2.26 to 1.20 t CO_2/tce. Notwithstanding this decrease in carbon intensity, there is an enormous potential for cutting down carbon dioxide emissions. This reduction can be realized through application of some policies and measures.

Several measures should be implemented by respective actors (enterprises and government) in order to reduce efficiently carbon dioxide emissions from the Chinese textile industry. Firstly, government should encourage industries to apply self-commitment initiative, which will lead to less carbon dioxide emissions and to reach industrial objectives through structural and technological adjustments. Results showed that energy intensity and industrial activity were responsible for the growth of CO_2 emissions. Lin et al. [31,32,36] found that there is an inverse relation between technology and energy intensity. In the same order, Wang et al. [37] argued that technology upgrading could simultaneously promote economic growth, improve the energy efficiency and reduce carbon intensity per unit of output. Therefore, it is necessary to strongly consider the technology upgrading as a necessary process to reduce the energy intensity by allocating more investment for energy conservative technologies. Technological improvement will not only reduce the energy intensity and carbon emissions, but will also improve the industrial productivity. Moreover, the government should promote a shift of product mix toward high value-added products with less energy intensity.

Secondly, it will be necessary to strengthen adjustments of the energy mix. Our study shows that it is an important factor to consider for carbon dioxide emissions mitigation. Given that coal will continue to be the principal energy source in the near future, it is however necessary to develop the use of other energy sources such as natural gas and develop alternative energies to the fossil fuel. In this aspect, incentive measures will be to totally suppress the controlled energy price mechanism.

Despite the positive expectations from voluntary actions, the Chinese government and control agencies should employ constraining measures to reach the target of emissions reduction. The government should impose sanctions and penalties to enterprises failing to act by rules in matter of energy and environmental policies. On the other side, application of incentives measures has also proven their utility. Proportionally integrated to the performance realized by firms for reducing their fossil fuel consumption, and carbon emissions, financial measures such as tax credits, subsidy and grants will contribute to motivate energy conservative actions as supported by Floros and Vlachou [38]. In general, evidence from this study clearly indicates that, the industrial activity in the textile industry strongly determines the energy consumption, yet the carbon dioxide emissions. Therefore, energy conservation and fuel diversification are clearly important instruments to consider in order to cut down carbon dioxide emissions.

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